Appendix E: Electrical Reliability Example

E-1. Description

The electrical one-line diagram of the example lock and dam electrical system is shown in Figure E-1. The mission reliability electrical subsystems were extracted from Appendix F. Several of the electrical blocks from Appendix F did not have failure rate data readily available. These blocks required further extrapolation to the extent that available failure rate data were available.

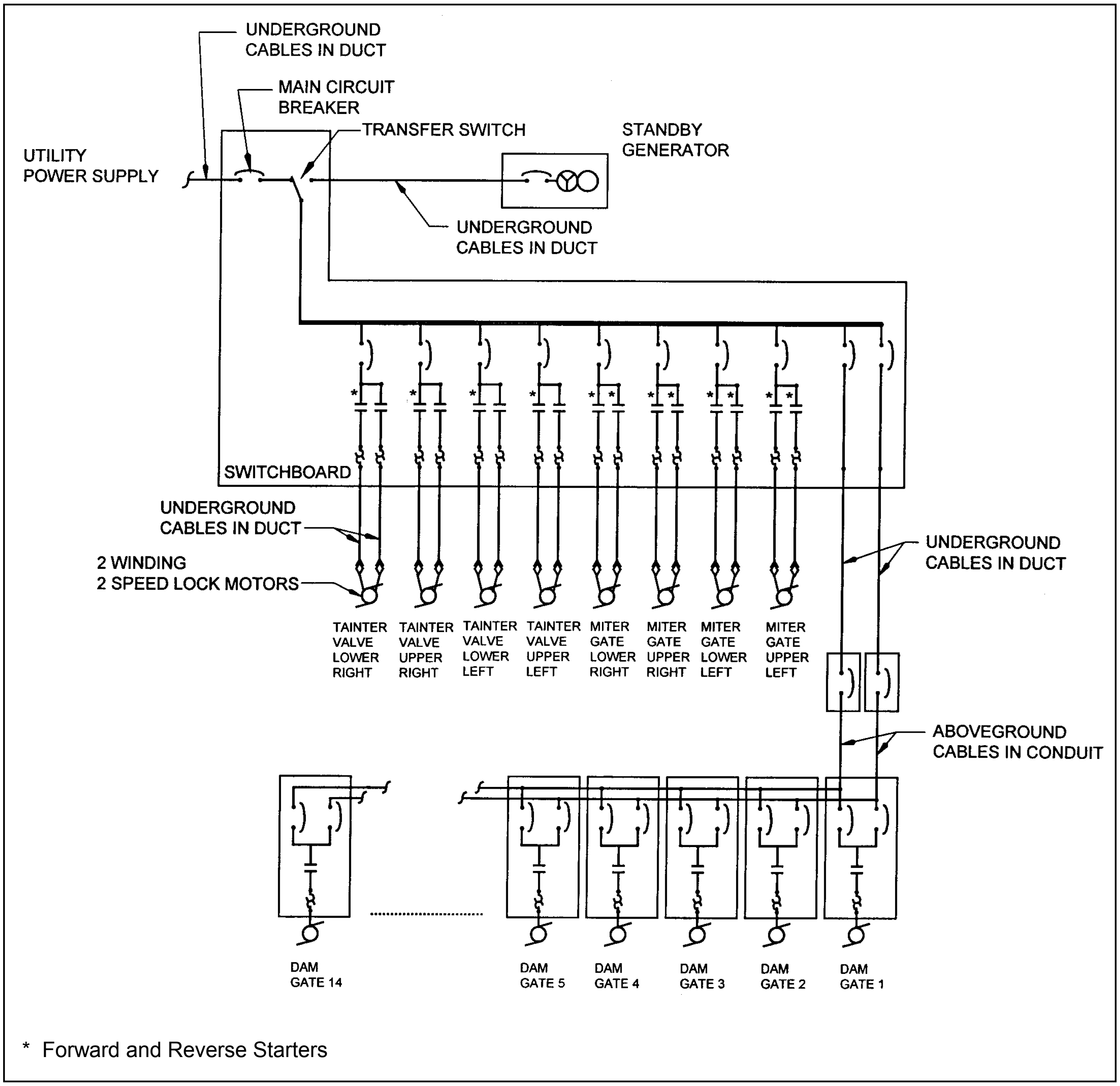

Figure E-1. Lock and dam electrical one-line diagram

E-2. Reliability Block Diagram Formulation

a. The normal electrical service (LAl) was arranged into a series connected block diagram that included the utility power supply, underground cables in duct, and a main circuit breaker as shown in Figure E-2. The resulting equation is

$$R_{SYS}(t) = R_A(t)*R_B(t)*R_C(t) \tag{E-1}$$

b. The standby service (LA2) was broken down into a series block diagram of the standby generator and underground cables in duct as shown in Figure E-3. The resulting equation is

$$R_{SYS}(t) = R_D(t)*R_B(t) \tag{E-2}$$

c. The automatic transfer switch (LB) and switchboard (LC) did not require additional refinement in the diagram because the reliability information for these items was readily available directly in published sources (Reliability Analysis Center 1995).

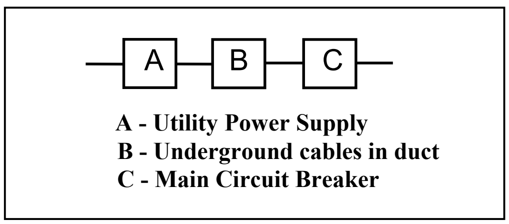

Figure E-2. Electrical service (LA1) block diagram

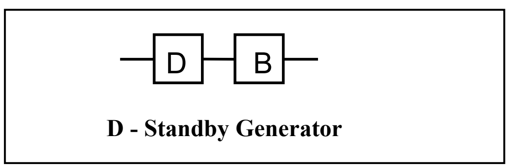

Figure E-3. Standby service (LA2) block diagram

d. The dam feeders and each of the lock gates and valves obtain their power from the switchboard located in the central control station. The two feeder blocks (DD1 and DD2) were connected in parallel to designate the redundancy of this subsystem. Each feeder was diagrammed as a series of blocks representing a molded case circuit breaker, underground cables in duct, another molded case circuit breaker, and aboveground cables in conduit, respectively, as shown in Figure E-4. The resulting equation is

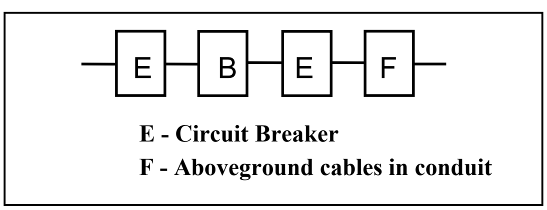

Figure E-4. Dam feeder (DD1 and DD2) block diagram

$$R_{SYS}(t) = R_E(t)*R_B(t)*R_E(t)*R_F(t) \tag{E-3}$$

e. Each lock gate (LD1, LD2, LD3, LD4) electrical equipment of Appendix F was extrapolated into appropriate components as a unique parallel-series block diagram. The diagram is shown in Figure E-5. The resulting equation is:

$$R_{SYS}(t) = R_M(t) * (1 - \{1 - [R_N(t)* R_O(t)* R_P(t)* R_Q(t)]\} * \{1 - [R_R(t)* R_S(t)* R_T(t)* R_U(t)]\}) \qquad \text{(E-4)}$$

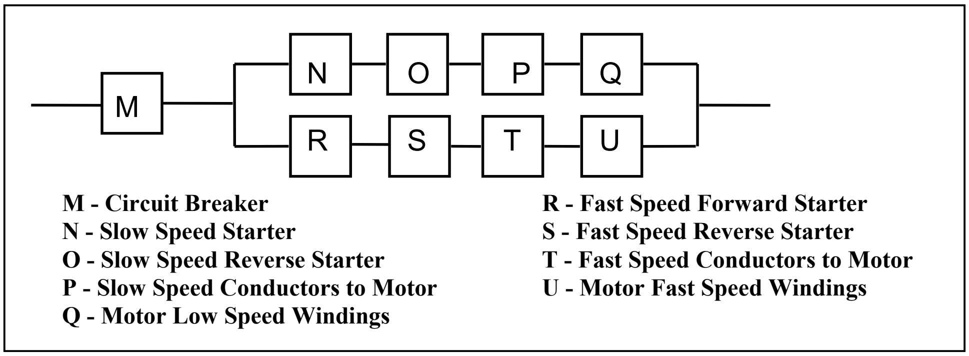

Figure E-5. Lock gate (LD) electrical mission reliability block diagram

f. The lock valve (LE1, LE2, LE3, LE4) electrical equipment was similar except the valves do not have slow speed reverse starter (O) (Figure E-6). The resulting equation is

$$R_{SYS}(t) = R_M(t) * (1 - \{1 - [R_N(t)* R_P(t)* R_Q(t)]\} * \{1 - [R_R(t)* R_S(t)* R_T(t)* R_U(t)]\}) \qquad \text{(E-5)}$$

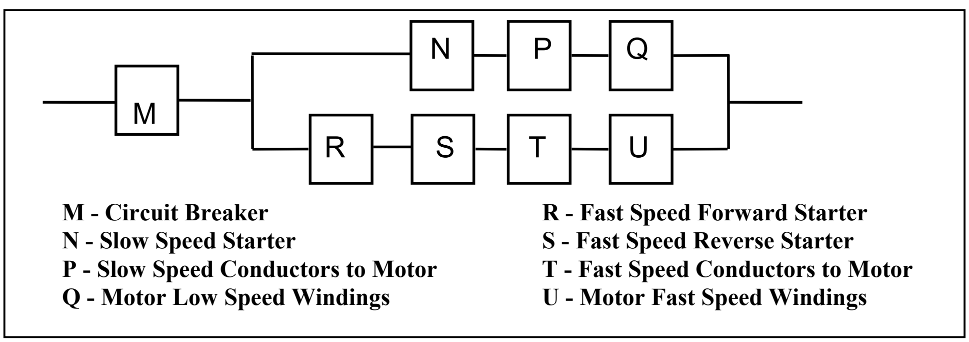

Figure E-6. Lock valve (LE) electrical mission reliability block diagram

g. The dam gate (DE1 through 14) electrical equipment was similar except the gates do not have slow speed starters, conductors, or windings (N, O, P, Q) and have parallel redundant circuit breakers (M) (Figure E-7).

h. The resulting equation is

$$R_{SYS}(t) = \{2*R_M(t)-[R_M(t)*R_M(t)]\}*R_R(t)*R_S(t)*R_T(t)* R_U(t) \qquad \text{(E-6)}$$

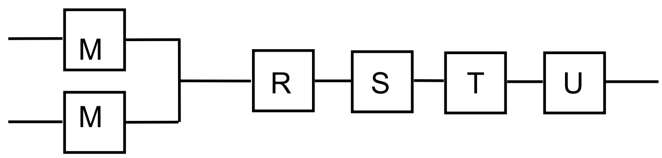

Figure E-7. Dam gate (DE) electrical mission reliability block diagram

E-3. Reliability Calculation

a. Environmental conditions. The environmental conditions were considered for the ambient service of the electrical equipment. Determination of the environmental K factor was the same as for the mechanical equipment (See paragraph D-3*b* and *c*). The electrical equipment on the lock and dam was considered to be exposed to an outdoor marine environment resulting in a K_1 factor of 2.

b. Failure rate. The failure rates of all applicable components were obtained from the published literature of American National Standards Institute/Institute of Electrical and Electronics Engineers (ANSI/IEEE) (1980) and Reliability Analysis Center (1995). Typical component failure rates from these two sources are provided in Tables E-1 and E-2, respectively. The typical failure rates were adjusted in the analysis to the environmental conditions of the lock.

$$\lambda' = \lambda K \tag{E-7}$$

where

λ' = adjusted failure rate

λ = typical failure rate

K = environmental factor = 2

c. Duty cycle.

(1) Failures of electrical equipment often correspond to voltage and/or current parameters. Failure rates are typically provided in "operating hours" or "experience hours," which by definition are a duration of exposure to voltage and/or current. Since voltage and current applied to equipment are near zero when they are not in operation, the total mission time was adjusted with a duty cycle factor. The duty cycle factor is the ratio of actual time the equipment is energized by voltage and/or current to the total mission time t:

$$t' = td \tag{E-8}$$

where

t' = adjusted time variable (i.e., operation time)

t = calendar time variable

d = duty cycle factor

For example, electrical equipment such as transfer switches are normally energized 100 percent of the calendar year resulting in a duty cycle of 1.0. However, the duty factor for lock gate and valve electrical equipment is directly related to the number of lockages or hard operations that occur at a facility. The number of lockages may vary over time, and hence the duty factor may vary. In this example, the lockages or cycles increase with time. The duty factor is calculated for each year as follows: For year 5, the lock performs 11,799 open/close cycles. Assuming the operating time of an open or close operation is 120 sec (or 240 sec for a combined open and close cycle) and using a total mission time of 8,760 hr per year then

Operating time = [(120 * 2) sec/cycle * 11,799 cycles/year] / 3600 sec/hr

= 786.6 operational hr/year

= 786.6/8760 hr/year

d = 0.0898

(2) Each component time variable was adjusted as applicable to its duty cycle. Even though the lock gates and valves are operated with a system duty cycle of 0.0898, the duty cycle for the gate and valve electrical equipment must account for the two-speed operation. The slow speed portion of each system operation is 3 sec/120 sec or 2.5 percent of the system duty cycle. The final duty cycle factor used to adjust the time variable for the slow speed components of the gate and valve equipment was 0.0022, and the associated high-speed factor was 0.0898 - 0.0022 = 0.0876. For forward and reverse starters the applicable duty factor was further reduced by 50 percent to compensate for the alternating use of the starters during a lockage cycle.

(3) The emergency generator duty cycle was calculated assuming a maximum standard operation of 2 hr in 24 hr (0.08). The dam gates were calculated at 0.007 as demonstrated in Appendix D. The dam feeders were calculated at 0.5 using an assumption that each feeder is alternately energized uniformly.

d. Distribution. The modes of failure for electrical equipment are very complex (i.e., they involve a wide variety of distresses such as temperature, vibration, mechanical stresses, etc.) resulting in an inability to select β values for a Weibull distribution. Since the values were not known, a value of 1.0 was used, which reduces the Weibull distribution equation to the exponential distribution for the computation of the reliability value. The exponential reliability equation is

$$R(t) = e^{-\lambda' t'} \qquad \text{(E-9)}$$

where

λ' = adjusted failure rate - failures/year

t' = adjusted time variable (operation time) - years

E-4. Results

The results for the electrical subsystems are shown in spreadsheet format in Tables E-3 through E-7. It is evident that the lock electrical distribution reliability is much less than that of any other electrical subsystem evaluated. This was attributed to the 100 percent demand on the major components of that subsystem and also its greater failure rate.

Table E-1
Failure Rate Data of Electrical Components from ANSI/IEEE (1980)

Component (Failures per Unit-Year)	Failure Rate per 10^6 Experience Hours
Electric Utility Power Supplies, Single Circuit (0.537)	61.3014
Transformers	
Liquid Filled, All (0.0041)	0.4680
Dry-Type (0.0036)	0.4110
Generator (Diesel or Gas Driven)	7.6500

Table E-2
Failure Rate Data of Electrical Components from Reliability Analysis Center (1995)

Component[1]	Failure Rate per 10^6 Operating Hours
Arrester, Surge	2.6988
Cable (Summary)	1.1383
Above Ground (in conduit)	0.0300
Above Ground (no conduit)	0.4311
Aerial	0.6516
Below Ground (in duct)	0.5988
Below Ground (in conduit)	0.1876
Below Ground (direct buried)	2.5417
Capacitor Bank	4.5913
Circuit Breaker (Summary)	1.7856
Molded case	0.3574
Electric Motor (Summary)	9.2436
AC	6.8834
DC	14.4367
Fuse (Summary)	2.5012
Receptacle (Summary)	2.2727
Starter (Summary)	0.7636
Motor	0.0212
Switch, Disconnect (Summary)	4.5645
Switchgear (Summary)	0.5830
Bus (Summary)	0.5051
Bare	0.3890
Insulated	0.7925
Switch, Transfer (Summary)	6.3978

[1] The summary data represent combined failure rate data merged from several different sources.

Table E-3
Reliability Analysis, Lock Electrical Distribution

Component/Block	Quan.	Failure Rate*	Weibull Shape Factor, β	Environmental K Factor	Adjusted Failure Rate	Duty Factor, d
Utility Power Supply	1	61.3014	1.0	2	122.6028	1.0000
Conductors in Duct	2	0.5988	1.0	2	1.1976	1.0000
Circuit Breaker	1	0.3574	1.0	2	0.7148	1.0000
Generator	1	7.6500	1.0	2	15.3000	0.0800
Transfer Switch	1	6.3978	1.0	2	12.7956	1.0000
Switchgear, Bus, Bare	1	0.5051	1.0	2	1.0102	1.0000

RELIABILITY [R(t)] OF INDIVIDUAL COMPONENTS

Years in Service (Equipment is installed at time 0)

	0	5	10	15	20	25	30	35	40	45	50
Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
Utility Power Supply	1.0000	0.0047	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Conductors in Duct	1.0000	0.9489	0.9004	0.8544	0.8107	0.7693	0.7300	0.6927	0.6573	0.6237	0.5918
Circuit Breaker	1.0000	0.9692	0.9393	0.9104	0.8823	0.8551	0.8287	0.8032	0.7784	0.7544	0.7312
Generator	1.0000	0.9478	0.8983	0.8514	0.8070	0.7649	0.7249	0.6871	0.6512	0.6172	0.5850
Transfer Switch	1.0000	0.5710	0.3260	0.1861	0.1063	0.0607	0.0346	0.0198	0.0113	0.0064	0.0037
Switchgear, Bus, Bare	1.0000	0.9567	0.9153	0.8757	0.8378	0.8015	0.7668	0.7336	0.7019	0.6715	0.6424

HAZARD RATES [h(t)] OF INDIVIDUAL COMPONENTS

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
Utility Power Supply	1.0740	1.0740	1.0740	1.0740	1.0740	1.0740	1.0740	1.0740	1.0740	1.0740	1.0740
Conductors in Duct	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105
Circuit Breaker	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063
Generator	0.1340	0.1340	0.1340	0.1340	0.1340	0.1340	0.1340	0.1340	0.1340	0.1340	0.1340
Transfer Switch	0.1121	0.1121	0.1121	0.1121	0.1121	0.1121	0.1121	0.1121	0.1121	0.1121	0.1121
Switchgear, Bus, Bare	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088

RELIABILITY OF SYSTEM [R_{sys}(t)]

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
	1.0000	0.8885	0.7631	0.6566	0.5649	0.4861	0.4182	0.3599	0.3096	0.2664	0.2292

* Failure Rate per 10^6 Operating Hours from Reliability Analysis Center (1995) and Appendix A of ANSI/IEEE (1980).

Table E-4
Reliability Analysis, Lock Miter Gate Electrical Equipment

Component/Block	Quan.	Failure Rate*	Weibull Shape Factor, β	Environmental K Factor	Adjusted Failure Rate
Circuit Breaker	1	0.3574	1.0	2	0.7148
Forward Starter, Fast	1	0.0212	1.0	2	0.0424
Reverse Starter, Fast	1	0.0212	1.0	2	0.0424
Conductors in Duct, Fast	1	0.5988	1.0	2	1.1976
Electric Motor, AC, Fast	1	6.8834	1.0	2	13.7668
Forward Starter, Slow	1	0.0212	1.0	2	0.0424
Reverse Starter, Slow	1	0.0212	1.0	2	0.0424
Conductors in Duct, Slow	1	0.5988	1.0	2	1.1976
Electric Motor, AC, Slow	1	6.8834	1.0	2	13.7668

DUTY FACTOR, d

Years in Service (Equipment is installed at time 0)

	0	5	10	15	20	25	30	35	40	45	50
Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
Number of Cycles**	12758	11799	12336	12514	12692	12841	12991	13249	13508	13754	14000
Circuit Breaker	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Forward Starter, Fast	0.0473	0.0438	0.0458	0.0464	0.0471	0.0476	0.0482	0.0492	0.0501	0.0510	0.0519
Reverse Starter, Fast	0.0473	0.0438	0.0458	0.0464	0.0471	0.0476	0.0482	0.0492	0.0501	0.0510	0.0519
Conductors in Duct, Fast	0.0947	0.0875	0.0915	0.0929	0.0942	0.0953	0.0964	0.0983	0.1002	0.1021	0.1039
Electric Motor, AC, Fast	0.0947	0.0875	0.0915	0.0929	0.0942	0.0953	0.0964	0.0983	0.1002	0.1021	0.1039
Forward Starter, Slow	0.0012	0.0011	0.0012	0.0012	0.0012	0.0012	0.0012	0.0013	0.0013	0.0013	0.0013
Reverse Starter, Slow	0.0012	0.0011	0.0012	0.0012	0.0012	0.0012	0.0012	0.0013	0.0013	0.0013	0.0013
Conductors in Duct, Slow	0.0024	0.0022	0.0023	0.0024	0.0024	0.0024	0.0025	0.0025	0.0026	0.0026	0.0027
Electric Motor, AC, Slow	0.0024	0.0022	0.0023	0.0024	0.0024	0.0024	0.0025	0.0025	0.0026	0.0026	0.0027

RELIABILITY [R(t)] OF INDIVIDUAL COMPONENTS

Years in Service (Equipment is installed at time 0)

	0	5	10	15	20	25	30	35	40	45	50
Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
Circuit Breaker	1.0000	0.9692	0.9393	0.9104	0.8823	0.8551	0.8287	0.8032	0.7784	0.7544	0.7312
Forward Starter, Fast	1.0000	0.9999	0.9998	0.9997	0.9997	0.9996	0.9995	0.9994	0.9993	0.9991	0.9990
Reverse Starter, Fast	1.0000	0.9999	0.9998	0.9997	0.9997	0.9996	0.9995	0.9994	0.9993	0.9991	0.9990
Conductors in Duct, Fast	1.0000	0.9954	0.9904	0.9855	0.9804	0.9753	0.9701	0.9645	0.9588	0.9530	0.9470
Electric Motor, AC, Fast	1.0000	0.9486	0.8955	0.8454	0.7968	0.7503	0.7056	0.6604	0.6166	0.5747	0.5345
Forward Starter, Slow	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Reverse Starter, Slow	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Conductors in Duct, Slow	1.0000	0.9999	0.9998	0.9996	0.9995	0.9994	0.9992	0.9991	0.9989	0.9988	0.9986
Electric Motor, AC, Slow	1.0000	0.9986	0.9972	0.9957	0.9942	0.9927	0.9911	0.9894	0.9877	0.9859	0.9841

HAZARD RATES [h(t)] OF INDIVIDUAL COMPONENTS

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
Circuit Breaker	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063
Forward Starter, Fast	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
Reverse Starter, Fast	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
Conductors in Duct, Fast	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105
Electric Motor, AC, Fast	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206
Forward Starter, Slow	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
Reverse Starter, Slow	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
Conductors in Duct, Slow	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105
Electric Motor, AC, Slow	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206

RELIABILITY OF SYSTEM [R_{sys}(t)]

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
	1.0000	0.9691	0.9390	0.9096	0.8811	0.8533	0.8262	0.7998	0.7742	0.7492	0.7249

PROBABILITY OF UNSATISFACTORY PERFORMANCE OF SYSTEM [1-R_{sys}(t)]

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
	0.0000	0.0309	0.0610	0.0904	0.1189	0.1467	0.1738	0.2002	0.2258	0.2508	0.2751

HAZARD RATE OF SYSTEM [h_{sys}(t)]

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
one gate	0.0063	0.0138	0.0215	0.0287	0.0357	0.0423	0.0486	0.0548	0.0609	0.0666	0.0721

* Failure Rate per 10^6 Operating Hours from Reliability Analysis Center (1995) and Appendix A of ANSI/IEEE (1980).

** Hard Cycles is approximation based on a linear regression of factual data from the year range of 1980 through 1997.

Table E-5
Reliability Analysis, Lock Tainter Valve Electrical Equipment

Component/Block	Quan.	Failure Rate*	Weibull Shape Factor, β	Environmental K Factor	Adjusted Failure Rate
Circuit Breaker	1	0.3574	1.0	2	0.7148
Forward Starter, Fast	1	0.0212	1.0	2	0.0424
Reverse Starter, Fast	1	0.0212	1.0	2	0.0424
Conductors in Duct, Fast	1	0.5988	1.0	2	1.1976
Electric Motor, AC, Fast	1	6.8834	1.0	2	13.7668
Forward Starter, Slow	1	0.0212	1.0	2	0.0424
Conductors in Duct, Slow	1	0.5988	1.0	2	1.1976
Electric Motor, AC, Slow	1	6.8834	1.0	2	13.7668

DUTY FACTOR, d

	Years in Service (Equipment is installed at time 0)										
	0	5	10	15	20	25	30	35	40	45	50
Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
Number of Cycles**	12758	11799	12336	12514	12692	12841	12991	13249	13508	13754	14000
Circuit Breaker	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Forward Starter, Fast	0.0473	0.0438	0.0458	0.0464	0.0471	0.0476	0.0482	0.0492	0.0501	0.0510	0.0519
Reverse Starter, Fast	0.0473	0.0438	0.0458	0.0464	0.0471	0.0476	0.0482	0.0492	0.0501	0.0510	0.0519
Conductors in Duct, Fast	0.0947	0.0875	0.0915	0.0929	0.0942	0.0953	0.0964	0.0983	0.1002	0.1021	0.1039
Electric Motor, AC, Fast	0.0947	0.0875	0.0915	0.0929	0.0942	0.0953	0.0964	0.0983	0.1002	0.1021	0.1039
Forward Starter, Slow	0.0024	0.0022	0.0023	0.0024	0.0024	0.0024	0.0025	0.0025	0.0026	0.0026	0.0027
Conductors in Duct, Slow	0.0024	0.0022	0.0023	0.0024	0.0024	0.0024	0.0025	0.0025	0.0026	0.0026	0.0027
Electric Motor, AC, Slow	0.0024	0.0022	0.0023	0.0024	0.0024	0.0024	0.0025	0.0025	0.0026	0.0026	0.0027

RELIABILITY [R(t)] OF INDIVIDUAL COMPONENTS

	Years in Service (Equipment is installed at time 0)										
	0	5	10	15	20	25	30	35	40	45	50
Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
Circuit Breaker	1.0000	0.9692	0.9393	0.9104	0.8823	0.8551	0.8287	0.8032	0.7784	0.7544	0.7312
Forward Starter, Fast	1.0000	0.9999	0.9998	0.9997	0.9997	0.9996	0.9995	0.9994	0.9993	0.9991	0.9990
Reverse Starter, Fast	1.0000	0.9999	0.9998	0.9997	0.9997	0.9996	0.9995	0.9994	0.9993	0.9991	0.9990
Conductors in Duct, Fast	1.0000	0.9954	0.9904	0.9855	0.9804	0.9753	0.9701	0.9645	0.9588	0.9530	0.9470
Electric Motor, AC, Fast	1.0000	0.9486	0.8955	0.8454	0.7968	0.7503	0.7056	0.6604	0.6166	0.5747	0.5345
Forward Starter, Slow	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Conductors in Duct, Slow	1.0000	0.9999	0.9998	0.9996	0.9995	0.9994	0.9992	0.9991	0.9989	0.9988	0.9986
Electric Motor, AC, Slow	1.0000	0.9986	0.9972	0.9957	0.9942	0.9927	0.9911	0.9894	0.9877	0.9859	0.9841

HAZARD RATES [h(t)] OF INDIVIDUAL COMPONENTS

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
Circuit Breaker	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063
Forward Starter, Fast	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
Reverse Starter, Fast	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
Conductors in Duct, Fast	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105
Electric Motor, AC, Fast	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206
Forward Starter, Slow	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
Conductors in Duct, Slow	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105
Electric Motor, AC, Slow	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206

RELIABILITY OF SYSTEM [$R_{sys}(t)$]

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
	1.0000	0.9691	0.9390	0.9096	0.8811	0.8533	0.8262	0.7998	0.7742	0.7492	0.7249

PROBABILITY OF UNSATISFACTORY PERFORMANCE OF SYSTEM [$1-R_{sys}(t)$]

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
	0.0000	0.0309	0.0610	0.0904	0.1189	0.1467	0.1738	0.2002	0.2258	0.2508	0.2751

HAZARD RATE OF SYSTEM [$h_{sys}(t)$]

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
one valve	0.0063	0.0138	0.0215	0.0287	0.0356	0.0422	0.0484	0.0547	0.0607	0.0665	0.0719

* Failure Rate per 10^6 Operating Hours from Reliability Analysis Center (1995) and Appendix A of ANSI/IEEE (1980).

** Hard Cycles is approximation based on a linear regression of factual data from the year range of 1980 through 1997.

Table E-6
Reliability Analysis, Dam Electrical Distribution

Component/Block	Quan.	Failure Rate*	Weibull Shape Factor, β	Environmental K Factor	Adjusted Failure Rate	Duty Factor, d
Circuit Breaker	2	0.3574	1.0	2	0.7148	0.5000
Conductors in Duct	1	0.5988	1.0	2	1.1976	0.5000
Conductors in Conduit	1	0.0300	1.0	2	0.0600	0.5000

RELIABILITY [R(t)] OF INDIVIDUAL COMPONENTS

Years in Service (Equipment is installed at time 0)

	0	5	10	15	20	25	30	35	40	45	50
Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
Circuit Breaker	1.0000	0.9845	0.9692	0.9541	0.9393	0.9247	0.9104	0.8962	0.8823	0.8686	0.8551
Conductors in Duct	1.0000	0.9741	0.9489	0.9243	0.9004	0.8771	0.8544	0.8323	0.8107	0.7897	0.7693
Conductors in Conduit	1.0000	0.9987	0.9974	0.9961	0.9948	0.9935	0.9921	0.9908	0.9895	0.9882	0.9869

HAZARD RATES [h(t)] OF INDIVIDUAL COMPONENTS

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
Circuit Breaker	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063
Conductors in Duct	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105
Conductors in Conduit	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005

RELIABILITY OF SYSTEM [R_{sys}(t)]

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
	1.0000	0.9428	0.8890	0.8382	0.7903	0.7451	0.7025	0.6624	0.6245	0.5888	0.5552

* Failure Rate per 10^6 Operating Hours from Reliability Analysis Center (1995) and Appendix A of ANSI/IEEE (1980).

Table E-7
Reliability Analysis, Dam Gate Electrical Equipment

Component/Block	Quan.	Failure Rate*	Weibull Shape Factor, β	Environmental K Factor	Adjusted Failure Rate	Duty Factor, d
Circuit Breaker	2	0.3574	1.0	2	0.7148	1.0000
Forward Starter	1	0.0212	1.0	2	0.0424	0.0035
Reverse Starter	1	0.0212	1.0	2	0.0424	0.0035
Conductors in Conduit	1	0.0300	1.0	2	0.0600	0.0070
Electric Motor, AC	1	6.8834	1.0	2	13.7668	0.0070

RELIABILITY [R(t)] OF INDIVIDUAL COMPONENTS

Years in Service (Equipment is installed at time 0)	0	5	10	15	20	25	30	35	40	45	50	63
Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2053
Circuit Breaker	1.0000	0.9692	0.9393	0.9104	0.8823	0.8551	0.8287	0.8032	0.7784	0.7544	0.7312	0.6740
Forward Starter	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9999	0.9999
Reverse Starter	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9999	0.9999
Conductors in Conduit	1.0000	1.0000	1.0000	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9998	0.9998	0.9998
Electric Motor, AC	1.0000	0.9958	0.9916	0.9874	0.9833	0.9791	0.9750	0.9709	0.9668	0.9627	0.9587	0.9482

HAZARD RATES [h(t)] OF INDIVIDUAL COMPONENTS

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2053
Circuit Breaker	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063
Forward Starter	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
Reverse Starter	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
Conductors in Conduit	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Electric Motor, AC	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206	0.1206

RELIABILITY OF SYSTEM [R_{sys}(t)]

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2053
	1.0000	0.9948	0.9879	0.9794	0.9695	0.9584	0.9462	0.9331	0.9191	0.9044	0.8891	0.8471

* Failure Rate per 10^6 Operating Hours from Reliability Analysis Center (1995) and Appendix A of ANSI/IEEE (1980).